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(71) Applicant(s)

Mark Carmichael  
34 Main Road, LUMPHANAN, Kincardineshire,  
AB31 4PX, United Kingdom

(72) Inventor(s)

Mark Carmichael

(74) Agent and/or Address for Service

Murgitroyd & Company  
373 Scotland Street, GLASGOW, G5 8QA,  
United Kingdom

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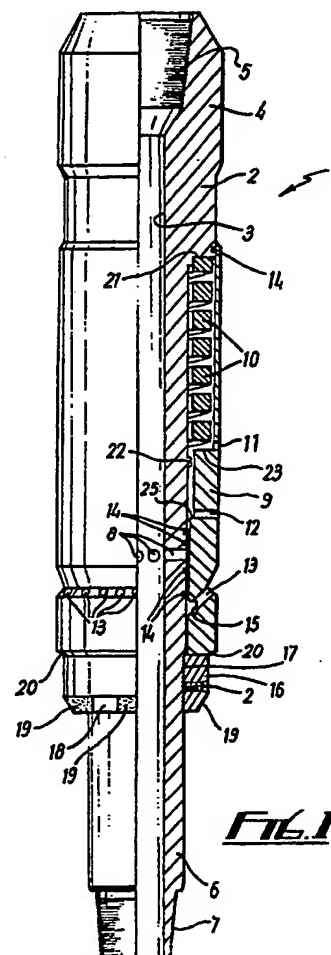
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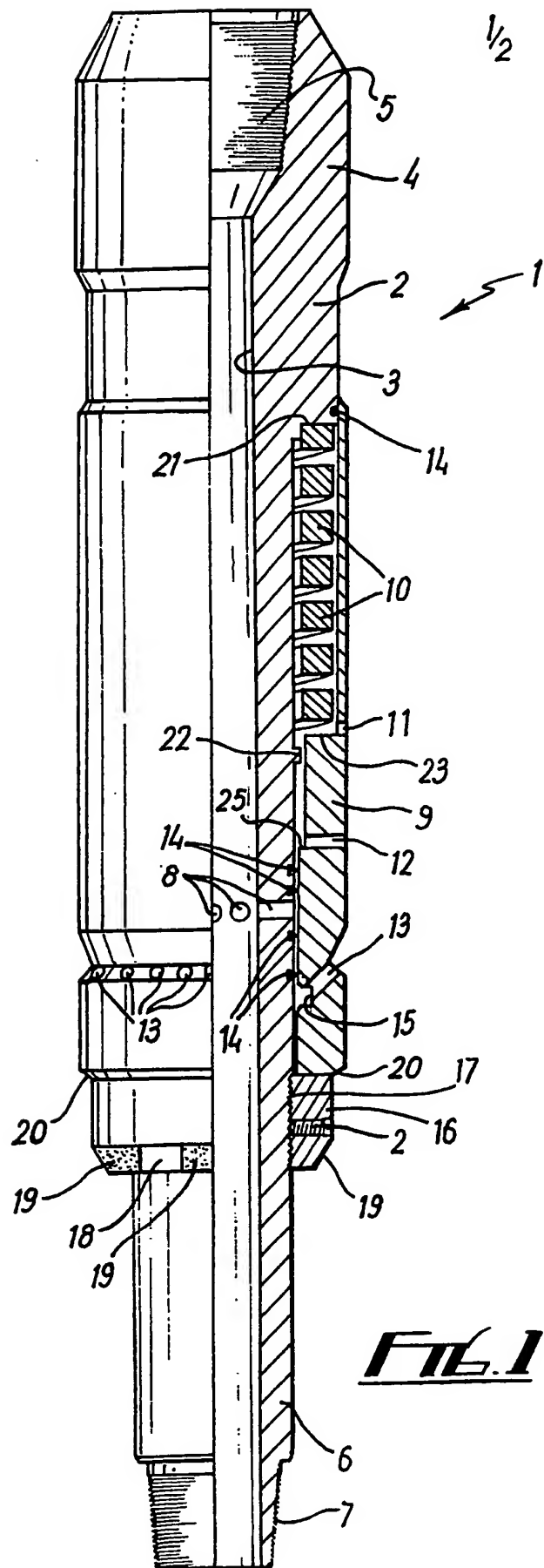
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INT CL<sup>5</sup> E21B

## (54) Apparatus for circulating fluid

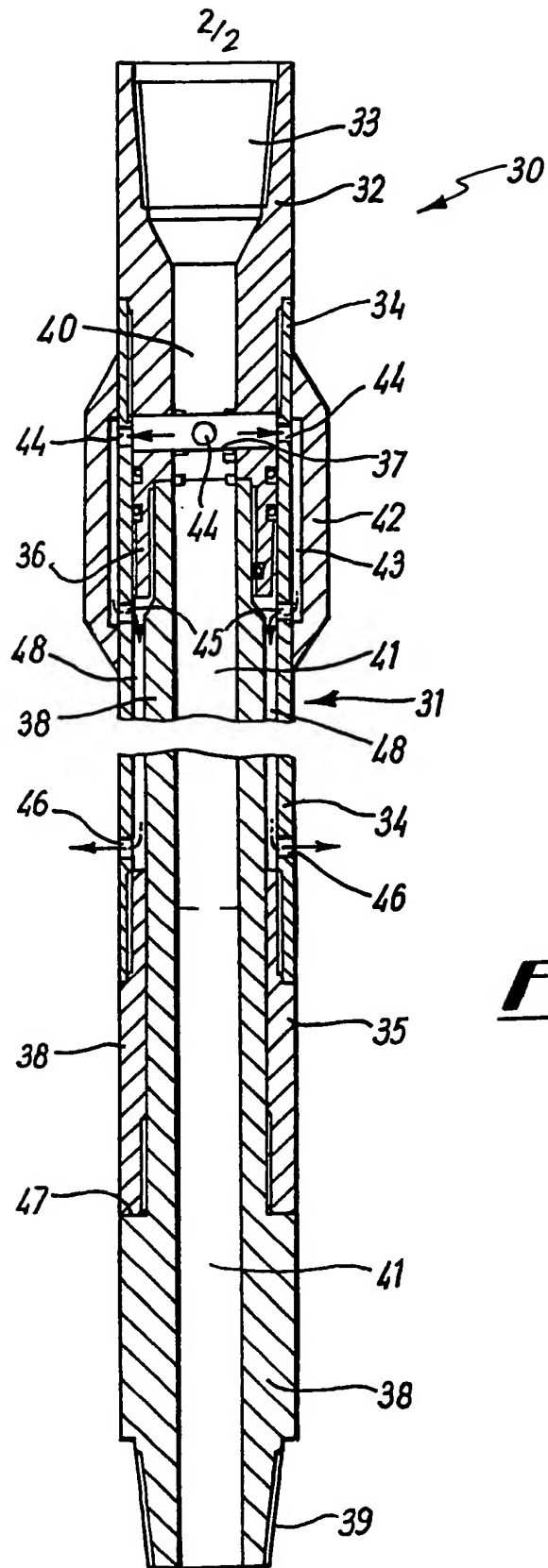
(57) Apparatus (1) for circulating fluid in a borehole comprises a body member (2) having a fluid outlet (8). An isolation sleeve (9) is movably mounted on the body member (2) for movement between an open position in which fluid may flow out of the outlet (8) and a closed position. The isolation sleeve (9) is moved to its open position against the action of spring 10 by engaging shoulder 20 with the top of the lining and setting down on the tubing string. In a second embodiment (not shown) the outlet is opened when the lower end of the tubing string engages the bottom of the borehole.



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**Fig. 1**



**FIG. 2**

1     "Apparatus for Circulating Fluid"

2

3     The invention relates to apparatus for circulating  
4     fluid and in particular, apparatus for circulating  
5     fluid in a borehole.

6

7     It is common practice to install liners within a  
8     borehole which has been drilled and after installation  
9     of the liners it is generally necessary to clean out  
10    the inside of the liner to wash away any debris or  
11    other contaminants.

12

13    Generally, the liner is in the form of a cylindrical  
14    tube which has a relatively small internal diameter  
15    compared with the diameter of casing lining the  
16    borehole immediately above the liner. To effectively  
17    clean out inside the liner, high flow rates are  
18    generally required to create turbulence to aid the  
19    cleaning out process. Generally, the clean out  
20    procedure is carried out by first passing cleaning  
21    liquid through the drill string to the lower end of the  
22    liner at a high flow rate so that the cleaning fluid  
23    flows turbulently up the annulus between the inside of  
24    the liner and the outside of the drill-pipe and then  
25    into the casing above the liner.

26

1     However, because of the difference in volume between  
2     the liner and the casing above the liner, after the  
3     cleaning fluid passes the top of the liner and enters  
4     the relatively large volume of the casing, the flow  
5     rate of the cleaning fluid in the casing above the  
6     liner is greatly reduced and any cleaning action  
7     becomes negligible.

8  
9     Hence, it is generally necessary after passing cleaning  
10    fluid through the liner to then pass further cleaning  
11    fluid from the drill-pipe into the casing at a location  
12    above or adjacent the top edge of the liner, so that a  
13    high flow rate and hence turbulence of the cleaning  
14    fluid can be obtained in the casing. Therefore it is  
15    generally necessary to have some device at or adjacent  
16    to the top end of the liner which can be operated  
17    downhole to either circulate fluid through the length  
18    of the drill string to the lower end of the liner or  
19    which can direct cleaning fluid at high flow rates out  
20    of the drill string into the casing above the liner, at  
21    or adjacent the top edge of the liner.

22  
23    Once such device that is known for carrying out this  
24    operation comprises a hollow body member and in order  
25    to change the direction of flow between the bottom of  
26    the liner and the top edge of the liner, spherical  
27    balls are dropped down the drill-string to open or  
28    close valves in the device.

29  
30    However, there are a number of disadvantages associated  
31    with this apparatus. In particular, the length of time  
32    associated with the spherical balls falling from the  
33    surface to the device through a drill-string which is  
34    perhaps a few thousand feet in length can take 25 to 30  
35    minutes. Hence, there is a problem with co-ordinating

1 the arrival of the spherical ball at the apparatus to  
2 coincide with the arrival of the required cleaning  
3 fluid at the apparatus. It is also necessary to ensure  
4 that the increasing and decreasing flow rates  
5 associated with the liner and the casing clean out are  
6 co-ordinated with the arrival of the spherical ball at  
7 the apparatus.

8  
9 In addition, it is generally necessary to repeat the  
10 cleaning out of the liner and the casing a number of  
11 times with different cleaning fluids until a situation  
12 is obtained in which the last clean out is carried out  
13 with sea water. Hence, it is necessary to be able to  
14 repeatedly operate the apparatus to divert flow between  
15 the lower end and upper end of the liner a number of  
16 times. With the apparatus described above there is the  
17 disadvantage that the apparatus is designed so that  
18 each spherical ball that is dropped down the drill-  
19 string changes the direction of clean-out liquid flow  
20 either from the lower end of the liner to the upper end  
21 or from the upper end of the liner to the lower end of  
22 the liner. Hence, the number of times which this  
23 apparatus can be used to cycle fluid between the lower  
24 and upper ends of the liner is limited by the design of  
25 the device and when the spherical balls have been used  
26 or the tool is full with spherical balls and cannot be  
27 cyclically operated further, it is necessary to extract  
28 the drill-string from the borehole in order to recover  
29 the device and remove the spherical balls from the  
30 device.

31  
32 In addition, there is also the danger that the  
33 spherical balls may not properly engage with the device  
34 and the risk that the device will not operate  
35 correctly.

1 In accordance with the present invention, there is  
2 provided apparatus for circulating fluid in a borehole,  
3 the apparatus having a fluid inlet and a first fluid  
4 outlet, the first fluid outlet communicating with the  
5 fluid inlet for throughflow of fluid through the  
6 apparatus, and the apparatus including:-

7 a body member having a second fluid outlet;  
8 an isolation means movably mounted on the body  
9 member for movement between an open position in which  
10 fluid introduced into the apparatus through the fluid  
11 inlet may flow out of the second outlet, and a closed  
12 position in which fluid is substantially prevented from  
13 flowing out of the second outlet; and

14 actuating means connected with one of the body  
15 member or the isolation means for coupling to a  
16 formation in the borehole to provide resistance to  
17 movement of the actuating means with respect to the  
18 formation, whereby movement of the other of the body  
19 member or the isolation means relative to the formation  
20 causes relative movement between the isolation means  
21 and the body member to move the isolation means between  
22 its open and closed positions.

23  
24 An advantage of the invention is that by providing an  
25 isolation means which is movable between a closed  
26 position and an open position and an actuating means  
27 which may be coupled to a formation in the borehole,  
28 circulation of fluid can be redirected by movement of  
29 one of the body member or isolation means relative to  
30 the formation. ✓

31  
32 Typically, the formation may be a shoulder portion in  
33 the borehole. Alternatively, the formation may be the  
34 bottom of the borehole, in which case the actuating  
35 means may be coupled to the formation by a string, such

1 as a drill string, on which the apparatus is run into  
2 the hole.

3

4 The apparatus may further include biasing means to bias  
5 the isolation means to the closed or open position.  
6 Typically, the biasing means is mounted on the body  
7 member. In the preferred example of the invention, the  
8 isolation means is biased to the closed position by the  
9 biasing means.

10

11 In one example of the invention, the isolation means  
12 prevents fluid passing through the second outlet by  
13 obturating the second outlet and typically, the  
14 isolation means could comprise a sleeve mounted on the  
15 body member. The isolation means may be mounted on the  
16 outside surface of the body member or on an inside  
17 surface of the body member.

18

19 In another example of the invention, the body member  
20 may include a by-pass channel and in the closed  
21 position the isolation means obturates the entrance  
22 and/or exit to the by-pass channel or the second  
23 outlet, while in the open position fluid may by-pass  
24 the isolation means by passing through the by-pass  
25 channel to reach the second outlet.

26

27 Preferably, the second outlet may comprise a number of  
28 apertures in the body member which communicate with the  
29 inlet and typically, the apertures may be distributed  
30 circumferentially around the outer surface of the body  
31 member.

32

33 Preferably, the fluid inlet and the first outlet are  
34 defined by a longitudinal throughbore in the body  
35 member and typically, the second outlet is defined by



1 at least one transverse bore extending from the  
2 throughbore to the outer surface of the body member.

3  
4 Typically, the cross-sectional area of the second  
5 outlet is greater than the cross-sectional area of the  
6 first outlet.

7  
8 Preferably, where the isolation means comprises a  
9 sleeve, the sleeve has a number of apertures therein  
10 which communicate with the second outlet when the  
11 isolation means is in the open position.

12  
13 Preferably, the second outlet is designed to  
14 communicate with the apertures in the sleeve  
15 irrespective of the circumferential orientation of the  
16 sleeve with respect to the second outlet. Typically,  
17 this may be provided by a circumferentially extending  
18 groove on the outer surface of the body member which  
19 communicates with the second outlet and is aligned with  
20 the apertures in the sleeve when the isolation means is  
21 in the open position. Alternatively, this could be  
22 designed by providing a circumferentially extending  
23 groove on the inside of the sleeve which communicates  
24 with the apertures in the sleeve and aligns with the  
25 second outlet when the isolation means is in the open  
26 position.

27  
28 Typically, movement of one of the body member or the  
29 isolation means towards the bottom of the borehole when  
30 the actuating means is coupled to the formation causes  
31 movement of the isolation means from the closed to the  
32 open position.

33  
34 Typically, the actuating means may comprise a shoulder  
35 which contacts a shoulder portion in the borehole.

1 Preferably, the shoulder portion in the borehole may be  
2 provided by the upper edge of a liner installed in the  
3 borehole.

4  
5 Preferably, a shoulder on the isolation means may have  
6 the surface which contacts the shoulder in the borehole  
7 and may have hard facing applied to it. The advantage  
8 of applying hard facing in this manner is that if the  
9 top edge of the liner has been damaged accidentally by  
10 running tools in and out of the liner, the hard facing  
11 can be used to redress the upper edge of the liner to  
12 ensure that the actuating means correctly engages with  
13 the top edge of the liner. Typically the hard facing  
14 could comprise tungsten carbide.

15  
16 Preferably, the cross-sectional area of the second  
17 outlet in the body member is greater than the total  
18 cross-sectional area of the apertures in the sleeve.  
19 This has the advantage that wear of the apertures in  
20 the sleeve is more likely to occur than wear of the  
21 second outlet and, hence the life of the body member is  
22 increased.

23  
24 Preferably, the apertures in the sleeve are designed to  
25 direct the fluid exiting the second outlet in an  
26 upwards direction into the casing.

27  
28 Two examples of apparatus for circulating fluid in a  
29 borehole in accordance with the invention will now be  
30 described with reference to the accompanying drawings,  
31 in which:-

32  
33 Fig. 1 is a partial cross-sectional view through a  
34 first example of a circulating tool; and  
35 Fig. 2 is a cross-sectional view through a second

1           example of a circulating tool.

2  
3       Fig. 1 shows a circulation tool 1 which comprises a  
4       body member 2 which has a throughbore 3 with a diameter  
5       of approximately 2.7". End 4 of the body member 2 has  
6       a female threaded coupling 5 and end 6 of the body  
7       member 2 has a male threaded coupling 7. In the  
8       central section of the body member are located twelve  
9       circumferentially distributed holes 8 and each hole has  
10      a diameter of 5/8" which gives a total cross-sectional  
11      area for the twelve holes 8 of approximately 3.68  
12      square inches.

13  
14      Slidably mounted on the outside surface of the body  
15      member 2 is a sleeve 9 which is biased against the body  
16      member 2 by means of a helical spring 10. Located in  
17      the sleeve 9 are two vent holes 11, 12 which permit the  
18      equalisation of pressures outside the sleeve 9 with  
19      pressures between the sleeve 9 and body member 2 in  
20      order to permit movement of the sleeve 9 relative to  
21      the body member 2. Also located in the sleeve 9 are  
22      eighteen circulating ports 13. The circulating ports  
23      13 each have a 1/2" diameter and therefore have a total  
24      cross-sectional area of approximately 3.53 square  
25      inches. Also mounted on the body member 2 to engage  
26      the sleeve 9 are five O-ring seals 14 which sealingly  
27      engage with the sleeve 9. On the inside of sleeve 9  
28      adjacent the circulating ports 13 is an internal groove  
29      15 formed in the inner surface of the sleeve 9.

30  
31      Below the sleeve 9 is a spring tensioner ring 16 which  
32      is threadedly engaged with the body member 2 through a  
33      thread formation 17. A set screw 18 is provided to  
34      lock the spring tensioner 16 in position on the body  
35      member 2.

1 The spring tensioner ring 16 has an angled shoulder 19  
2 to which hard facing in the form of tungsten carbide  
3 hard facing 20 is applied in four equally spaced  
4 circumferential locations on the shoulder 19. At the  
5 lower end of the sleeve 9, adjacent the spring  
6 tensioner ring 16, an actuating shoulder 21 is  
7 provided.

8  
9 For assembly of the tool 1, the helical spring 10,  
10 which in this example has a length of  $10\frac{1}{2}$  inches and a  
11 spring rating of 1,680 lbs per inch, is slid onto the  
12 body member 2 over the end 6 and located between  
13 shoulder 21 and lug 22 on the body member 2. The  
14 O-rings 14 are located in their respective grooves and  
15 the sleeve 9 is then slid onto the body member 2, until  
16 shoulder 23 on the sleeve abuts against the lower end  
17 of the spring 10. The spring tensioner ring 16 is then  
18 slid over the end 6 of the body member 2 and the thread  
19 formations 17 engaged. The spring tensioner ring 16 is  
20 then screwed up to the lower end of the sleeve 9 and  
21 tightened to compress the spring 10 and move the spring  
22 and sleeve 9 to the position shown in Fig. 1. In the  
23 example shown, this will give a tension of  
24 approximately 1,500 lbs in the spring 10 when the  
25 apparatus is in the position shown in Fig. 1.

26  
27 In operation, the tool 1 is connected via the male  
28 connector 7 to the upper end of a drill-string and  
29 further lengths of drill-pipe are connected to the  
30 upper end 4 of the tool 1 using the female connector 5.  
31 The drill-string and tool 1 are lowered into a borehole  
32 until the spring tensioner ring 16 enters the upper end  
33 of a liner in the borehole and shoulder 20 on the  
34 sleeve 9 rests against the upper edge of the liner.  
35

1 If the upper edge of the liner in the borehole has been  
2 damaged and the spring tensioner ring will not enter  
3 the liner, then the hard facing 19 on the shoulder 18  
4 of the spring tensioner ring 16 will contact the  
5 damaged sections of the liner and rotation of the  
6 drill-string will cause rotation of the spring  
7 tensioner ring 16 to redress the upper edge of the  
8 liner by the abrasive action of the hard facing 19 on  
9 the upper edge of the liner.

10

11 The tension of the spring 10 when the sleeve 9 is in  
12 the position shown in Fig. 1 is such that the shoulder  
13 20 can contact the upper edge of the liner without  
14 causing compression of the helical spring 10 and  
15 movement of the sleeve 9 upwards. Hence, initially the  
16 tool when the shoulder 20 contacts the upper edge of  
17 the liner remains in the position shown in Fig. 1.

18

19 In this position, the holes 8 in the body member 2 are  
20 obturated by the sleeve 9 and fluid can be pumped  
21 through the bore 3 in the tool 1 via the drill-string  
22 to exit the tool 1 through the end 6 into the drill-  
23 string below. Hence, fluid is pumped down the drill-  
24 string to the lower end of the liner to clean out the  
25 liner below the tool 1.

26

27 After the liner has been cleaned out, sufficient load  
28 is applied to the body member of the tool 1 to overcome  
29 the tension in the helical spring 10 and to cause  
30 movement of the body member 2 into the liner while the  
31 sleeve 9 rests on the upper edge of the liner. Travel  
32 of the sleeve 9 on the outside surface of the body  
33 member 2 is limited by shoulder 25 on the sleeve 9  
34 which abuts against the lug 22 on the body member.  
35 This helps prevent the spring 10 becoming spring bound.

1 When the shoulder 25 abuts against the lug 22 the  
2 groove 15 is adjacent the holes 8 in the body member 2  
3 so that the holes 8 communicate with the circulating  
4 ports 13.

5  
6 When the sleeve is in this second open position, fluid  
7 is free to pass from the throughbore 3 of the body  
8 member 2 and out through the holes 8 and circulating  
9 ports 13 into the casing without entering the liner.  
10 The upward facing direction of the circulating ports 13  
11 helps to reduce the possibility of any damage occurring  
12 to the casing due to the fluid exiting the circulating  
13 ports 13 horizontally.

14  
15 The advantage of the groove 15 is that irrespective of  
16 the orientation of the circulating ports 13 relative to  
17 the holes 8, fluid will pass through the holes 8 and  
18 out of the circulating ports 13 via the groove 15.

19  
20 Furthermore it will be noted that the total cross-  
21 sectional area of the circulating ports 13 is less than  
22 the total cross-sectional area of the holes 8. Hence,  
23 any wear due to fluid flow is more likely to occur on  
24 the circulating ports 13 which will only require  
25 replacement of the sleeve 9. As the sleeve 9 is less  
26 costly than the body member 2 this gives a cost  
27 efficient design.

28  
29 In order to start circulating fluid to the bottom of  
30 the liner again, the holes 8 can be obturated by  
31 reducing the load on the body member 2 of the tool 1 so  
32 that the tool 1 reverts to the position shown in Fig. 1  
33 and fluid can be circulated through the drill-string to  
34 the lower end of the liner for cleaning out the liner  
35 again.

1 In addition, a pressure operated valve could be coupled  
2 to the lower end 6 of the body member to positively  
3 isolate the lower length of drill-string from the  
4 through bore 3. As the flow rates of fluid will be  
5 higher when cleaning out the casing, such a valve could  
6 be designed to close above a given threshold pressure  
7 and open when pressure falls below this threshold.

8  
9 Fig. 2 shows a second example of a circulating tool 30  
10 which comprises a body member 31. The body member 31  
11 comprises a top sub 32 having a female threaded end 33.  
12 Threadedly engaged with the lower end of the top sub 32  
13 is a main sub 34 and threadedly engaged with the lower  
14 end of the main sub 34 is a bottom sub 35. Slidably  
15 mounted within the central sub 34 is a piston assembly  
16 36 which has a throughbore 37 in its upper end.  
17 Threadedly connected to the piston assembly 36 is the  
18 upper end of an inner mandrel 38. The lower end of the  
19 mandrel 38 protrudes from the end of the bottom sub 35  
20 and the lowermost end of the mandrel 38 has a male  
21 threaded connection 39. The top sub 32 has a  
22 throughbore 40 which communicates with the throughbore  
23 37 in the piston assembly 36 and a throughbore 41 in  
24 the mandrel 38.

25  
26 As shown in Fig. 2, the main sub 34 has a channel  
27 member 42 located on its outer surface and which  
28 defines a channel 43 which extends from ports 44 in the  
29 side wall of the main sub 34 to ports 45 also in the  
30 side wall of the main sub 34. Located further down the  
31 main sub 34 are outlet ports 46 in the lower end of the  
32 main sub 34.

33  
34 In use, the tool 30 is coupled into a drill string at  
35 the appropriate depth and may also have a pressure

1     operated valve coupled to the connection 39 of the  
2     mandrel 38.

3  
4     In order to pump fluid through the tool 30 to exit  
5     through the bore 41 in the mandrel 38, the drill string  
6     above the top sub 32 is lifted and the weight of the  
7     drill string below the mandrel 38 causes the piston  
8     assembly 36 and the inner mandrel 38 to stay stationary  
9     with respect to the borehole and the body member 31  
10    moves upwards until the top end of the bottom sub 35  
11    abuts the lower end of the piston assembly 36. In this  
12    position the outlet ports 46 are obturated and fluid  
13    within the tool 30 is prevented from exiting through  
14    the ports 46 so that fluid pumped into the tool 30 must  
15    pass through the bore 41 and into the drill string  
16    below the tool 30 to the lower end of the liner to  
17    clean out the liner below the tool 30.

18  
19    After the liner has been cleaned out, the drill string  
20    above the tool 30 can be lowered causing the body  
21    member 31 to move relative to the piston assembly 36  
22    and mandrel 38 until the lower end of the bottom sub 35  
23    rests against shoulder 47 on the mandrel 38, so that  
24    the tool 30 is in the position shown in Fig. 2. In  
25    this position, fluid pumped into the tool 30 may by-  
26    pass the piston assembly 36 by means of the ports 44,  
27    45 and the channel 43 to enter an annulus 48 between  
28    the main sub 34 and the mandrel 38. Hence, fluid may  
29    pass out of the outlet ports 46 to the casing without  
30    entering the liner.

31  
32    The advantage of tool 30 shown in Fig. 2 is that it  
33    does not require a shoulder on the top of the liner in  
34    order to actuate the tool, as the tool may be actuated  
35    by resting the end of the drill string on the bottom of



1 the borehole and increasing or decreasing the tension  
2 appropriately in order to move the body member 31 up or  
3 down with respect to the piston assembly 36 and the  
4 mandrel 38. However, it would also be possible to use  
5 the tool 30 in combination with a shoulder in the  
6 borehole, such as the top of a liner by connecting a  
7 tool with a shoulder, such as the spring tensioner ring  
8 16 shown in Fig. 1, around the mandrel 38.

9  
10 Hence, the invention has the advantages of permitting  
11 circulation of fluids to separate regions in a borehole  
12 by increasing or decreasing the load exerted on the  
13 tools 1, 30 in the borehole. Hence, the tools 1, 30  
14 have the advantage of operating when the load is  
15 increased or decreased without any effective time delay  
16 and also have the advantage that they facilitate  
17 circulation of the fluid between the two regions  
18 repeatedly without any limitation on the number of  
19 times recirculation can be achieved.

20  
21 Modifications and improvements may be incorporated  
22 without departing from the scope of the invention.

23  
24

1     CLAIMS

2

3     1.   Apparatus for circulating fluid in a borehole, the  
4     apparatus having a fluid inlet and a first fluid  
5     outlet, the first fluid outlet communicating with the  
6     fluid inlet for throughflow of fluid through the  
7     apparatus, and the apparatus including:-

8         a body member having a second fluid outlet;

9         an isolation means movably mounted on the body  
10        member for movement between an open position in which  
11        fluid introduced into the apparatus through the fluid  
12        inlet may flow out of the second outlet, and a closed  
13        position in which fluid is substantially prevented from  
14        flowing out of the second outlet; and

15        actuating means connected with one of the body  
16        member or the isolation means for coupling to a  
17        formation in the borehole to provide resistance to  
18        movement of the actuating means with respect to the  
19        formation, whereby movement of the other of the body  
20        member or the isolation means relative to the formation  
21        causes relative movement between the isolation means  
22        and the body member to move the isolation means between  
23        its open and closed positions.

24

25     2.   Apparatus according to claim 1, wherein the  
26     actuating means comprises a shoulder which engages a  
27     shoulder portion in the borehole.

28

29     3.   Apparatus according to claim 1 or claim 2, wherein  
30     the isolation means obturates the second outlet when in  
31     the closed position.

32

33     4.   Apparatus according to any of the preceding  
34     claims, wherein the body member includes a channel  
35     which extends across the isolation means when the

1 isolation means is in the open position.

2

3 5. Apparatus according to any of the preceding  
4 claims, wherein the fluid inlet and the first outlet  
5 are co-axial and the second outlet is transverse to the  
6 fluid inlet and the first outlet.

7

8 6. Apparatus according to any of the preceding  
9 claims, wherein the cross-sectional area of the second  
10 outlet is greater than the cross-sectional area of the  
11 first outlet.

12

13 7. Apparatus according to any of the preceding  
14 claims, wherein the isolation means comprises a sleeve.

15

16 8. Apparatus according to any of the preceding  
17 claims, wherein movement of one of the body member and  
18 the isolation means towards the bottom of the borehole,  
19 with the actuating means coupled to the formation moves  
20 the isolation means from the closed to the open  
21 position.

22

23 9. Apparatus according to any of the preceding  
24 claims, wherein the actuating means is connected with  
25 the isolation means and movement of the body member  
26 relative to the formation causes movement of the  
27 isolation means between the open and closed positions.

28

29 10. Apparatus for circulating fluid in a borehole,  
30 substantially as hereinbefore defined with reference to  
31 the accompanying drawings.

32

33

**Patents Act 1977**  
**Examiner's report to the Comptroller under Section 17**  
**(The Search report)**

17.

Application number  
GB 9323599.2

**Relevant Technical Fields**

- (i) UK Cl (Ed.M)      EIF (FGL, FLJ, FLP)  
(ii) Int Cl (Ed.5)      E21B

Search Examiner  
D J HARRISON

Date of completion of Search  
16 FEBRUARY 1994

**Databases (see below)**

- (i) UK Patent Office collections of GB, EP, WO and US patent specifications.

Documents considered relevant following a search in respect of Claims :-  
1 TO 10

(ii)

**Categories of documents**

- X:** Document indicating lack of novelty or of inventive step.      **P:** Document published on or after the declared priority date but before the filing date of the present application.
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- A:** Document indicating technological background and/or state of the art.      **&:** Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	GB 545271 A	(CUTHILL & OIL WELL ENGINEERING CO) - whole document, but see particularly page 3 lines 73-94	1, 3, 5, 7, 9
X	US 4637471 A	(SODERBERG) - whole document	1, 5, 6, 9
X	US 4315542 A	(DOCKINS Jr) - whole document	1, 3, 5, 7, 9
X	US 3907046 A	(GAYLORD) - whole document, but see particularly column 4 lines 15-30	1, 3, 5, 7, 8, 9

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